

Solar Magnetic Drivers of Space Weather

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LONG-TERM GOAL

Our major goal is to improve the accuracy and timeliness of solar magnetic field data that are used to predict space weather disturbances that affect Earth.

OBJECTIVES

Our two primary scientific objectives are to provide best estimates of the magnetic flux distribution along the central meridian of the sun as a function of time, and also best estimates of the magnetic flux over the entire surface of the sun as a function of time. These data are required as boundary conditions for numerical models that are used to predict space weather conditions. Our secondary objectives are to explore poorly understood aspects of the solar magnetic field that may have future significance in understanding and predicting space weather. The specific targets are the polar magnetic field, the intranetwork magnetic field, and field configurations associated with coronal mass ejections.

APPROACH

For the primary objectives, the approach is to write new computer codes to process daily observations taken at the National Solar Observatory on Kitt Peak. These codes correct a number of known problems with earlier programs as well as moving into a new regime by adding evolution of magnetic field patterns. Once an observation is acquired, it is processed and a large number of data products produced. These data are made available to anyone via the Internet. All this happens within a few hours so that predictions can be promptly made. The approach for the secondary objectives is classical basic research. Namely, test hypotheses about a phenomenon against actual observations.

WORK COMPLETED

During the second year of this three-year grant, we implemented new codes to produce best estimates of the magnetic flux distribution along the solar central meridian on a daily basis and made these daily results available to researchers via the Internet. The data were used by Mikic and Linker to successfully

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predict the configuration of the solar corona at the time of an eclipse. Regarding studies of the polar magnetic flux distribution, we investigated the effects of the inclination of magnetic fields away from photospheric concentrations on observations of polar magnetic flux. We studied the systematic tilt of the polar magnetic fields and also deduced the polar rotation period as a function of latitude. Regarding studies of the intranetwork magnetic fields, we devised a method to calibrate image quality based on small-scale photospheric structure and used this to normalize measurements made over a number of years. The properties of the intranetwork magnetic field as functions of time and latitude were investigated. Their association with transient, bright emission features in the solar atmosphere was also studied. Regarding studies of magnetic fields associated with coronal mass ejections, we discovered large-scale, diffuse, mainly horizontal magnetic fields in the chromosphere underlying solar filaments that are often associated with coronal mass ejections.

RESULTS

The new maps of the distribution of magnetic flux along the central meridian as a function of time are superior to previous products. Making the results widely available within a few hours after the observations works well. A remaining difficulty is correcting the polar magnetic field from the observed line-of-sight component to magnetic flux passing through the surface. We determined an empirical correction based on the assumption that the flux should not depend on the direction to earth. In the course of this work we found that the polar fields around time of minimum solar activity are systematically tipped away from the poles and also toward the west for reasons that are not clear. We concluded that the empirical correction would not be constant over the course of the solar activity cycle and therefore abandoned it. In the past we, and others, have used simple extrapolations of the lower latitude fields to the poles, but this is not very satisfactory. Our work on constructing maps of the magnetic flux over the entire surface of the sun as a function of time points to a more satisfactory solution discussed below.

Progress toward our major goal, specifying a best estimate of the true flux distribution over the whole solar surface at a given instant of time, was unexpectedly rapid. This was thanks to close interactions between Dr. John Worden (supported by this grant) and Dr. Nick Arge (supported by an SR grant to NOAA). These discussions led to the concept of modeling the evolution of the surface magnetic field on a daily basis (or whenever new observations become available) using methods pioneered by NRL scientists N. Sheeley and Y.-M. Wang. In this method, we start from an initial estimate of magnetic flux on the entire solar surface at a certain time. When a new observation is available, the old map is evolved forward in time to the instant of the new observation which is then added into the map with high weight. The process continues as new data continue to be accumulated. In this way, we have a map of the solar surface that best approximates the true flux distribution on the sun at the time the latest observation was made. The success or failure of this method depends on the algorithms used to simulate the evolution of magnetic flux at the solar surface. We use established rules for differential rotation and meridional flow and, on average, these rules work fine. But two major evolutionary factors are the dispersion and disappearance of surface magnetic flux, and the rules governing these processes are not well understood. To date we assume that when opposite polarity flux moves close together there is a certain probability of it algebraically canceling. The dispersion, or local motion, is modeled by generating random arrays of accumulators on the solar surface which act to attract flux elements over short time periods. This method is tested and tuned by comparing the evolved field with actual observations. So far the results are quite encouraging.

Our analysis of the intranetwork magnetic field shows that it does not vary by a large amount, if at all, over the course of several years. There are some hints that it shows some latitude variation, but our observations of this are marginal. A second study showed that numerous, small, bright emission elements that are ubiquitous in the upper photosphere are not associated with the intranetwork magnetic field elements. On the other hand, the study found a fairly good association with the less numerous bright elements found in the chromosphere.

The polar magnetic field is important because it is the main pathway between the sun and the heliosphere during years of low sunspot activity. We found by combining many months of observations that the polar magnetic field is systematically tipped about one degree away from the poles and about the same amount toward the direction of rotation. The first result is not a surprise, but the second one is contrary to naive expectations and is not understood. In collaboration with Chinese colleagues, we determined the lifetime of the polar magnetic field elements to be as long as two days, and we used these features to get a good measurement of the rotation rate of the polar regions.

Recent work on the origins of coronal mass ejections suggests that a magnetic field change may be involved. Considering that the field changes thought to be associated with solar flares have not been unequivocally demonstrated, it is a severe observational challenge to see the likely much weaker changes associated with coronal mass ejections. While this goal is still elusive, we accidentally discovered that there are large-scale, diffuse, mainly horizontal magnetic fields in the chromosphere in regions thought to be the birth sites of prominence eruptions known to be associated with coronal mass ejections. This new magnetic field pattern is under investigation and may offer new insights, and possibly predictive potential, in the study of coronal mass ejections.

IMPACT/APPLICATIONS

The new maps of solar magnetic flux will provide superior predictions of space weather effects on earth. A substantial improvement in time resolution is welcome since solar activity is becoming more vigorous and the old assumption of slow changes in the magnetic field is becoming increasingly incorrect. We are intrigued by the diffuse chromospheric magnetic fields and will concentrate on possible signatures of impending coronal mass ejections that might be associated with these fields.

TRANSITIONS

Our data are being used as inputs to numerical models by the NRL Solar Physics Branch (Code 7660 - Wang and Sheeley), the Air Force Phillips Lab (Space Effects Division - Webb and Kahler), the NOAA Space Environment Center (Rapid Prototyping Center - Pizzo and Arge), and the SAIC Applied Physics Operation (Solar Physics Group - Linker and Mikic). In addition, our data products are accessed and used by observatories and researchers around the world.

RELATED PROJECTS

We are working closely with Nick Arge and Vic Pizzo at NOAA (who are supported by an ONR SR grant) to ensure that our new data products best meet their needs for their real-time prediction work. We have also shared data and techniques with Todd Hoeksema (Stanford University - Wilcox Solar Observatory) who produces data similar to ours under an ONR SR grant.

PUBLICATIONS

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- <http://www.nso.noao.edu/synoptic/synoptic.html/>. This web page shows the latest observations that are available from NSO Kitt Peak.
- <http://www.nso.noao.edu/synoptic/maps.html/>. This web page contains links to maps of the solar magnetic field along the central meridian as a function of time, The maps are updated whenever a new observation becomes available.